Fabrication of Thin Film Electroluminescent Devices for Display Applications

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Abstract – A preliminary effort in Electroluminescent (EL) device fabrication at Rochester Institute of Technology's Microelectronic Engineering Fabrication Facilities was attempted in this study. The fabrication of several AC driven electroluminescent devices, on silicon substrates were studied. Devices were fabricated on heavily doped p-type silicon, with tantalum pentaoxide dielectric and various phosphor materials. No working devices were fabricated in this initial attempt. However, deeper understanding of the functionality of each layer was gained.

I. INTRODUCTION

Flat-panel displays (FPDs) are becoming an integral part of the semiconductor industry. Trends in information technology and the demand for better visual communication are driving the development of new display technologies. As a much welcomed replacement for the traditional Cathode Ray Tube (CRT), flat panel displays offer the advantages of higher resolution, compactness and are light in weight. Many common applications of flat-panel displays are camcorder viewfinders, medical displays, public display screens and avionics.

Several dominant flat-panel display technologies exist including Liquid Crystal Displays (LCD), Plasma Displays, Field Emission Displays (FED) and Electroluminescent Displays (EL). In light of this, EL displays present a most attractive technology choice due to their compatibility with solid state technology, and wide viewing angle capability. EL Displays rely on light emission, rather than light reflection as in the case of LCD displays. Such that light is emitted from the devices, and a much wider viewing angle is obtained.

Complete integration of EL Display technology is contingent upon developing "phosphor" or the light emitting materials used in the image production. An EL display pixel consists of several electroluminescent devices, where each of these devices can emit a different color of light upon the application of voltage, and the chemistry of the phosphor. A standard pixel has a blue, red and green light emitters which culminate together to form 1 pixel.

In general, electroluminescence is the conversion of electrical energy into luminous energy, where the phosphor is the source of light generation. The phosphor is designed on the atomic level, to undergo various carrier recombination mechanisms, that aid in the emission of carriers and thus produce light. These mechanisms are outlined in Figure 1.

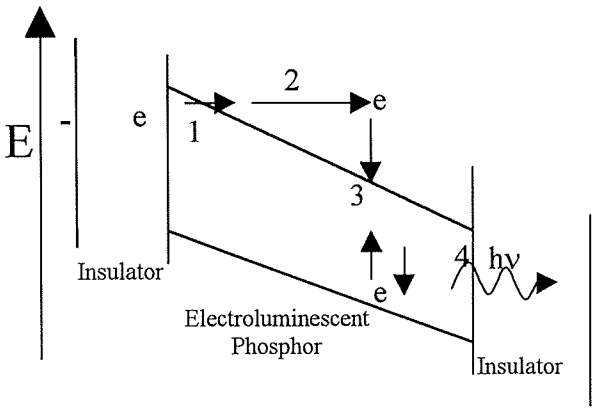

Figure 1: Electroluminescece Device Physics Mechanisms

Upon applying an AC voltage, carriers are injected into the phosphor from the insulator, recombine and are emitted through the transparent electrode. The insulator limits the current injected into the device which enhances lifetime. Mechanism 1 in the figure corresponds to the tunnel emission of electrons from the phosphor/insulator interface. Once these electrons are emitted, they are accelerated to high energies under the influence of the electric field in the phosphor as shown in mechanism 2. At mechanism 3, the high energy electrons impact the luminescent centers in the phosphor , and excite to a higher state. As the electron relaxes to a lower energy state, a photon is give off as shown in mechanism 4.

The functionality of the EL device depends heavily on optimizing both the optical and electrical film properties. The dielectric properties are most influential in device performance. High electric fields must be maintained for device operation and the ILD must be able to withstand these fields without breakdown. In addition to high breakdown strength, high permittivity is desired to maximize the field across the phosphor.

II. EXPERIMENTAL PROCEDURES

The EL devices were fabricated on p^{++} silicon substrates and consist of several thin film layers as shown in Figure 2. The structure includes a top electrode, two ILDs (inter-layer dielectric films) and a phosphor film sandwiched between the two ILDs. The top electrode serves as a contact to the device for voltage application. Since this is a luminescent device, the electrode must be transparent, and is therefore made of indium tin oxide (ITO). The bottom electrical contact is the p++ wafer.

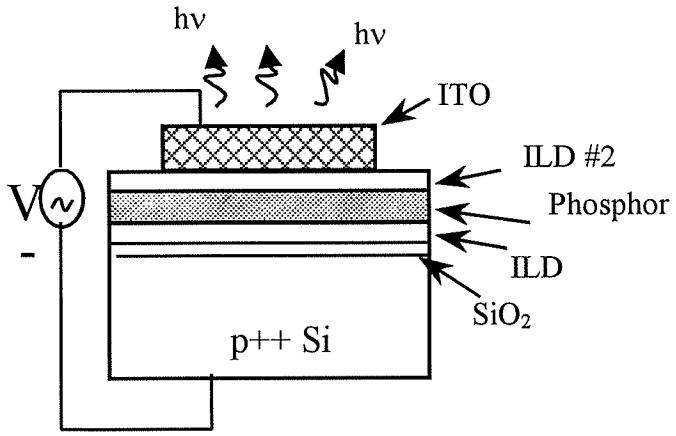

Figure 2: EL Device Cross Section

The two inter-layer dielectric films of Ta_2O_5, serve as current limiters into the phosphor. Tantalum oxide does not adhere well to silicon, so initially, a 500 Angstrom thermal pad oxide film was grown on the p++ wafer. The tantalum oxide was deposited next by DC reactive sputtering on a CVC 601 sputter tool. A 4" Tantalum target with gas flows 35 sccms of oxygen and 80 sccms of argon were used. Variable power and pressure conditions were used to attain different film characteristics as outlined in Table 1. After DC sputtering the first layer tantalum oxide film, the film was annealed for 30 minutes in a Thermco Diffusion furnace to turn the amorphous as deposited film, into a crystalline film.

Other tantalum oxide deposition process conditions examined were static vs. rotational deposition, and single vs. double layer tantalum films. With rotational deposition, the substrates rotate around the target during the deposition. In a static deposition, the substrate sits directly over the target and a much thicker film can be deposited. Also, a double layer tantalum oxide process was examined. A single layer of tantalum oxide is deposited and annealed, then a second tantalum oxide layer is deposited on top of that, as sort of a capping layer. The results of both processes will be discussed later.

	FilmA	FilmB	FilmC	FilmD	FilmE
Power (W)	650	300	500	500	600
Deposition Time (minutes)	40	55	60	55	55
O2/Ar Flows (sccms)	35/80	35/80	35/80	35/80	35/80
Chamber Pressure (mT)	3.2	3.8	2.8	2.8	2.7
Deposition Method	Rotation	Rotation	Static	Rotation	Rotation
Number of TaO Layers	1	1	1	1	2
Thickness (A)	1500	1200	10,000	5000	10,000
Breakdown Voltage (V)	Film Conductiv	8	4.5	45	180

Table 1: Tantalum Oxide Process Conditions

After the dielectric deposition and annealing, the phosphor film is put down next. Three different phosphor films were examined for this study:

(1) $Ta_2Zn_3O_8$ an experimental blue light emitter
(2) ZnS:Mn a known yellow light emitter
(3) SrS:Ce a known blue-green light emitter.

Phosphor #1 was deposited at the RIT Microelectronics Facilities by RF sputter of zinc oxide, overtop a tantalum oxide film on a Perkin Elmer RF Sputter System. A rapid thermal step was performed using AG Associates Rapid Thermal Anneal Tool to thermally activate the films to form $Ta_2Zn_3O_8$, the phosphor, on zinc oxide whose function is unknown. The other two phosphors were deposited at Georgia Tech's Phosphor labs under confidential process conditions.

After phosphor deposition, the 2nd ILD is deposited using the same process conditions as ILD #1 and annealed. Finally, the top electrode of Indium

Tin Oxide is deposited also using the CVC 601 DC Sputter Tool. The process conditions were 30 sccms of oxygen and 190 sccms of Argon (total pressure 5 mT), at power of 100 W, for 60 minutes. The film was then annealed on a hotplate at 250°C for 1 minute to make the film transparent and conductive.

A summary of the process flow is shown in Table 2.

Process Flow
1. Scribe Wafers
2. Pre-Diffusion Clean (RCA Clean)
3. Pad Oxide Growth (500 A)
4. Backside Wafer Clean
5. Sputter 1st Dielectric, Ta_2O_5
6. Anneal in Dry O_2 Ambient
7. Deposit Phosphor Film
8. Anneal Phosphor by RTP
9. Deposit 2nd Dielectric, Ta_2O_5, and anneal
10. Deposit Indium Tin Oxide (ITO) with shadow mask
11. Anneal ITO
12. Device Test

Table 2: EL Device Process Flow

The device testing included breakdown testing of the dielectric, and AC operational testing of the complete structure. Dielectric testing was completed on a Sony 370 Curve Tracer. Aluminum was shadow masked deposited onto a test wafer with a Ta_2O_8 film. An AC voltage signal was generated and applied to the aluminum contacts, and increased until breakdown. A similar test strategy was employed for the testing of the complete device, noting the threshold voltage for light emission.

II. RESULTS AND DISCUSSION

Optimization of the tantalum oxide film for maximum breakdown voltage is very critical for device operation. High electric fields must be excited across the phosphor layer, and the dielectric must be strong enough to withstand these fields. Table 1 previously listed results of several process variations for the deposition. For a single tantalum oxide layer (Films A-D), low breakdown voltages were seen, in comparison to a double tantalum oxide layer (Film E).

Some of the issues experienced for the single tantalum oxide process were high leakage, unverifiable dielectric constant, poor uniformity and conductive films as in Film A. For thinner films, the breakdown voltage is much lower. As an alternative, a static deposition process was investigated to achieve thicker films. Although the deposited film was much thicker, it exhibited poorer uniformity and stoichiometry, as seen by "bubbling" effect seen across the center of the wafer. This can possibly be contributed to the film being too thick, and upon annealing, the tantalum and oxygen sites did not settle well and experience stress. This ultimately leads to preferential sites for breakdown. The maximum single layer film breakdown voltage was seen in Film D of 45 V.

Previous work was completed in double layer tantalum processes. This concept was further explored for application to EL device dielectrics in hopes of achieving a higher dielectric breakdown. This process increased the breakdown to 180V, a much favored value and acceptable for the EL device structure.

After much experimentation with the tantalum oxide process as previously discussed, 3 final EL structures were evaluated. As mentioned previously, Georgia Tech Phosphor labs were of assistance in providing phosphor samples. A completed EL device was provided for baseline comparison to our fabricated devices. A comparison of the 3 fabricated structures is shown in Table 3.

Device A
• RIT Dielectric Layers
• ILD #1 & #2- Thin (Film B)
• $Ta_2Zn_3O_8$ Phosphor (RIT)
• Breakdown at 80 V
Device B
• RIT Dielectric Layers
• ILD #1 - Thin (Film B)
• ILD #2 – Double (Film E)
• SrS:Ce Phosphor (Ga. Tech)
• Breakdown at 90 V
Device C
• Complete EL structure from Ga. Tech
• ZnS:Mn Phosphor
• Proprietary Dielectric
• Threshold for light emission- 170V
• Breakdown at 350V

Table 3: Fabricated EL Device Structures

Device A was fabricated early on before realizing the poor breakdown properties of the single layer tantalum oxide process. Both dielectric layers of this device were thin, as defined in Table 1 as Film B, approximately 1200 Angstroms thick. In testing, the device was conducting under reverse bias only. The device broke down at 80 V, and subsequently no

light emission. On average, the threshold voltage for ac thin-film EL devices light emission is about 150 V which this device could not sustain.

Device B had a thin bottom dielectric (ILD #1 of Film B) and a double layer top dielectric (ILD #2 of Film E). The I-V characteristics of this device were slightly improved, and breakdown was at 90V. However, still not enough to reach the light emission voltage threshold.

Device C was a completely fabricated device supplied by Georgia Tech. This device functioned as expected and it's luminescence data is shown in Figure 3.

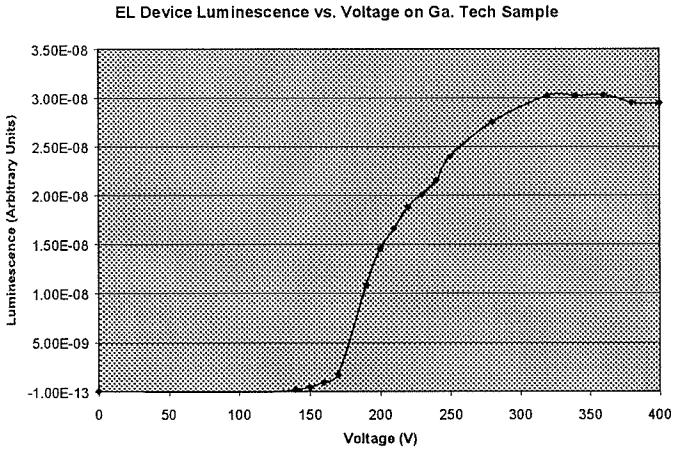

Figure 3: Luminescence Characteristics of Device C

The threshold voltage was 170 V for light emission, where the luminescence saturates at 300 V. The luminescence was measured using a International Light Corp. Radiometer, measured in arbitrary light units.

If devices A and B sustained high enough electric fields for the phosphor excitation and light emission, similar plots would have been produced.

IV. CONCLUSION

This work signifies the first process development for electroluminescent devices attempted at RIT. Several EL devices were fabricated, but with no successful emission of light. The poor quality tantalum oxide dielectric was found to be the limiting factor for light emission, where as the devices experienced dielectric breakdown before the effects of the phosphor luminescence can be realized. Strides have been made in realizing a good deposition process for tantalum oxide. A double layer film provided the best results. Further work with the optimized double layer tantalum oxide process will ideally yield satisfying results, and superlatively, light emission.

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